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ABSTRACT

The Marlowe Monte-Carlo backscattering code has been used to calculate particle reflection coefficients and energy distributions for H, D incident upon Li, K, Ni, Cu, Mo, Ag, Cs, Hf, W, Pt, and U surfaces. The backscattered energy and angular distributions are combined with a model for formation and survival probabilities for H^-, D^- leaving the surface. A least-squares fit of experimental measurements of H^- yields from the composite surface, Cs/Cu, has been used to obtain two semi-emperical constants α, β which enter into the formation and survival probabilities. These probabilities are used to calculate the production probability which in turn provides an upper limit to the negative ion yield. The choice of electrode material is discussed as a function of atomic number.

A MODEL FOR H^- AND D^- PRODUCTION BY HYDROGEN BACKSCATTERING

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We have developed a model for H^- and D^- production by hydrogen backscattering from alkali metal surfaces and alkali/transition-metal composite surfaces, Schneider (1980), Hiskes (1979), Schneider <u>et al</u> (1977), Hiskes and Karo (1977a, 1977b). In its essential form, the negative-ion-secondary emission coefficient (NISEC) is taken to be the product of the reflected particle velocity and angle distributions, the formation probability for negative ions, and the survival probability of negative ions as they move to great distances away from the surface.

For the optimization of negative hydrogen ion sources that utilize surface production phenomena, Leung and Ehlers (1979), it is necessary to select surface materials with high particle reflectivity together with low surface work function. In this paper we discuss the particle reflection properties of several possible cathode materials, and develop the model for the NISEC of the composite surface, Cs/Cu.

For the backscattered energy and angular distribution data we have recourse to the Marlowe Monte-Carlo particle reflection code of Robinson and Torrens (1974), and Oen and Robinson (1976). The energy or velocity distribution function and the angular distribution function for normal incidence can be factored according to

$$F(v,\theta)\, dvd(\cos\theta) = f(v)\, \cos\theta\, dvd(\cos\theta) \tag{1}$$

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The fraction of incident particles reflected by the crystal is then

$$R_N = \iint f(v) \cos\theta \, dv \, d(\cos\theta) \quad . \tag{2}$$

The reflected fraction versus atomic number for several electrode materials is shown in figure one for incident deuterium energies of 50, 100, 150, and 300 eV. Positive ion species D_3^+, D_2^+, and D^+ from the ion source discharge strike the active electrode material with equivalent deuterium kinetic energies of eV/3, eV/2, and eV, respectively, where V is the discharge-cathode potential.

Inspection of figure one shows that for incident deuterium energies of 300 eV the reflected fraction increases rapidly with atomic number up to about Z = 50 and remains roughly constant for higher Z. The choice of the optimum electrode material among the higher atomic number elements above Z = 50 can be made independently of reflection considerations. For lower incident energies the asymptotic reflectivity is achieved at considerably lower atomic number. For 50 eV incident particles the reflectivity of such low-Z materials as Ni and Cu are already large enough to be attractive to the source designer.

The energy distributions of the reflected particles are more sharply peaked toward the incident energy for high atomic number materials and for lower incident energies. In figures two and three are shown the energy distributions obtained from Marlowe for 50 eV and 300 eV deuterium particles incident normally on Cu, Mo, and W crystals. The data presented here were obtained using the polycrystalline option available in Marlowe.

In figure four is shown a polar plot of the angular distribution of the backscattered particles for 50 or 300 eV deuterium normally incident on tungsten. The 50 eV data is shown on the left, the 300 eV data on the right. Both distributions are normalized at 0^{o}, and each refers to the backscattered distribution obtained using 1000 incident particles. The 300 eV data is approximated by the cosine curve but the 50 eV data is more peaked toward the normal than is the cosine distribution. The trend toward a more peaked distribution at lower energies is a prevalent feature of Marlowe angular distributions, Oen and Robinson (1976).

The experimental data is analyzed using the expression

$$NISEC(E_i) = 2 \iint f_i(v) \cos\theta \left[1-e^{-\frac{\alpha}{v\cos\theta}}\right] e^{-\frac{\beta}{v\cos\theta}} dvd(\cos\theta) \quad . \tag{3}$$

The factor in the integrand

$$\left[1-e^{-\frac{\alpha}{v\cos\theta}}\right] e^{-\frac{\beta}{v\cos\theta}} \quad , \tag{4}$$

is referred to as the production probability and in turn is composed of two factors: formation and survival probability. The quantity α which occurs in the formation probability and the quantity β in the survival probability are treated as adjustable parameters and obtained by a least-squares fit of expression (3) to data points on the left hand side of the equation; Schneider (1980), Hiskes (1979). The velocity distributions, $f_i(v)$, are derived from Marlowe.

In figure five are shown experimental values of Schneider et al (1977) for the NISEC in the case of hydrogen incident upon a partial monolayer coverage of cesium over copper. The cesium coverage reduces the magnitude of the surface work function but is too thin to contribute appreciably to the backscattering. The least-squares fits shown in the figure are obtained using the Marlowe backscattering distributions, $f_i(v)$, for a Cu target.

Once the α, β have been obtained from the least-squares fit one can construct the formation, survival, and production probabilities as shown in figure six. The formation probability approaches unity at low energies and the survival probability tends toward unity at high energies. The production probability is a maximum for a perpendicular energy near 30 eV and is the limiting yield that could be achieved by total reflection of the incident particles at the optimum reflected energy.

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FIGURE CAPTIONS

Figure 1. The reflected fraction, R_N, versus atomic number for deuterium incident normally at either of several energies: ∇-50 eV; ▲-100 eV; □-150 eV; ●-300 eV.

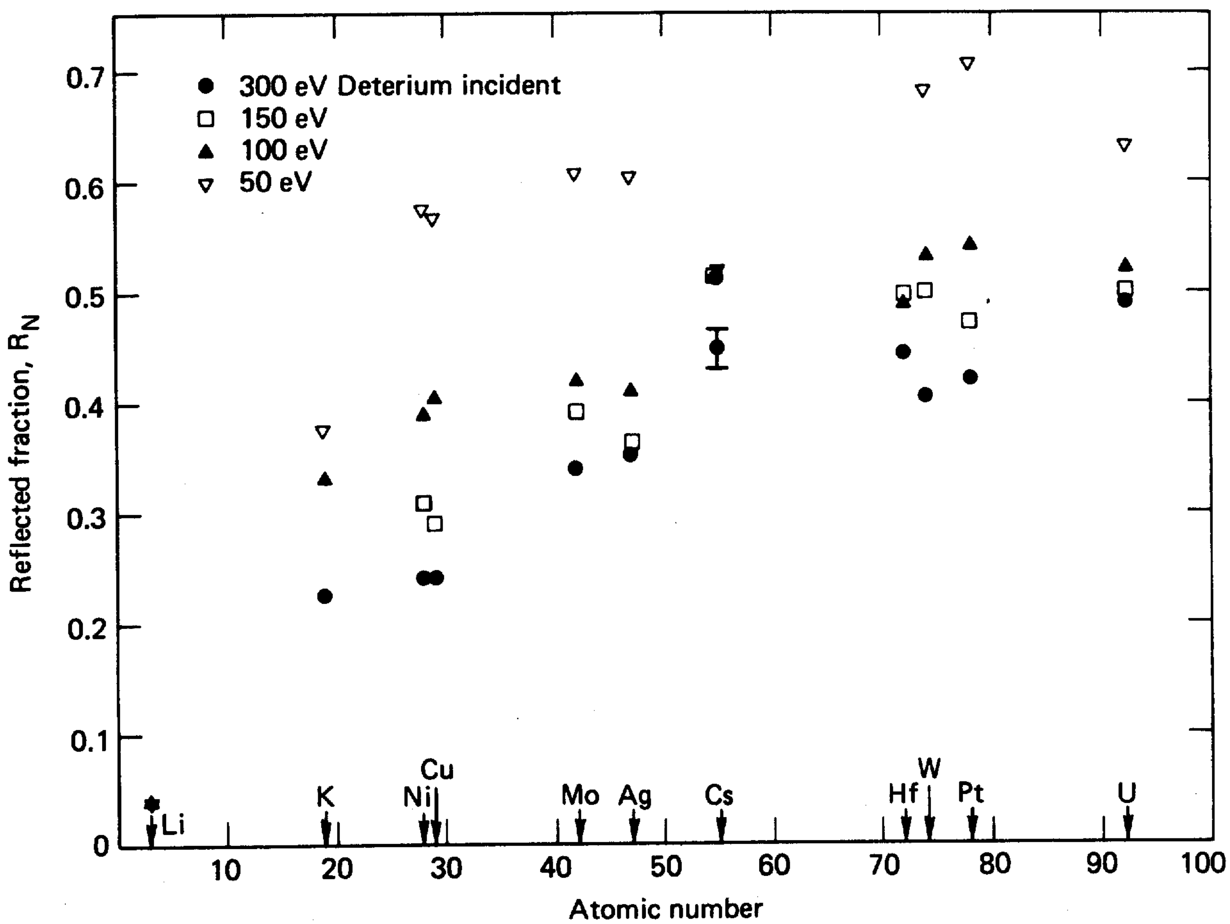
Figure 2. Histograms of the backscattered energy distribution versus backscattered energy for 50 eV deuterium incident normally upon Cu, Mo, and W targets.

Figure 3. Histograms of the backscattered energy distribution versus backscattered energy for 300 eV deuterium incident normally upon Cu, Mo, and W targets.

Figure 4. Polar plot of the angular distribution of backscattered particles for 50 eV and 300 eV deuterons incident normally upon W. The polar angle is measured away from the normal. The circle represents a cosine distribution. Data points on the left pertain to 50 eV deuterons, those on the right 300 eV deuterons.

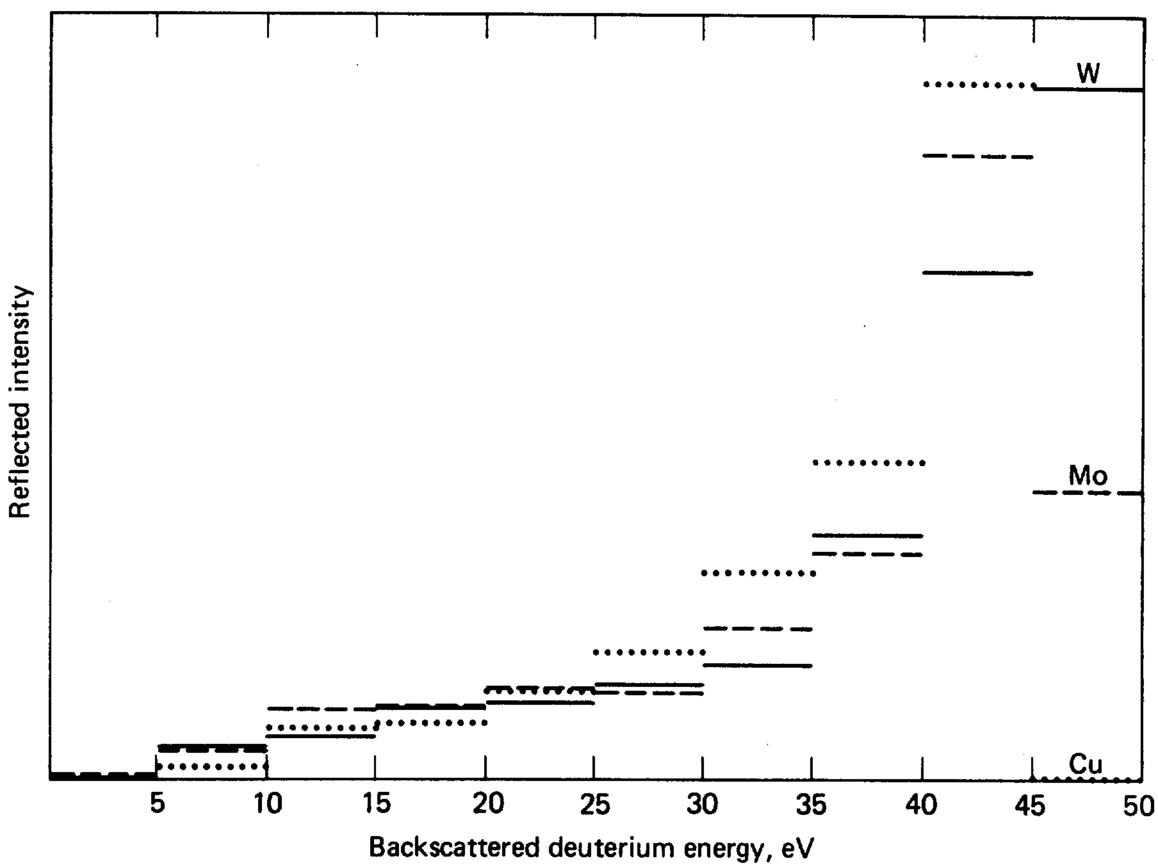
Figure 5. NISEC yields for hydrogen incident normally upon a composite surface of a partial monolayer coverage of Cs on Cu. Circles - exp. data; crosses - least-squares fits.

Figure 6. The formation, survival, and production probabilities derived from the data of figure 5.



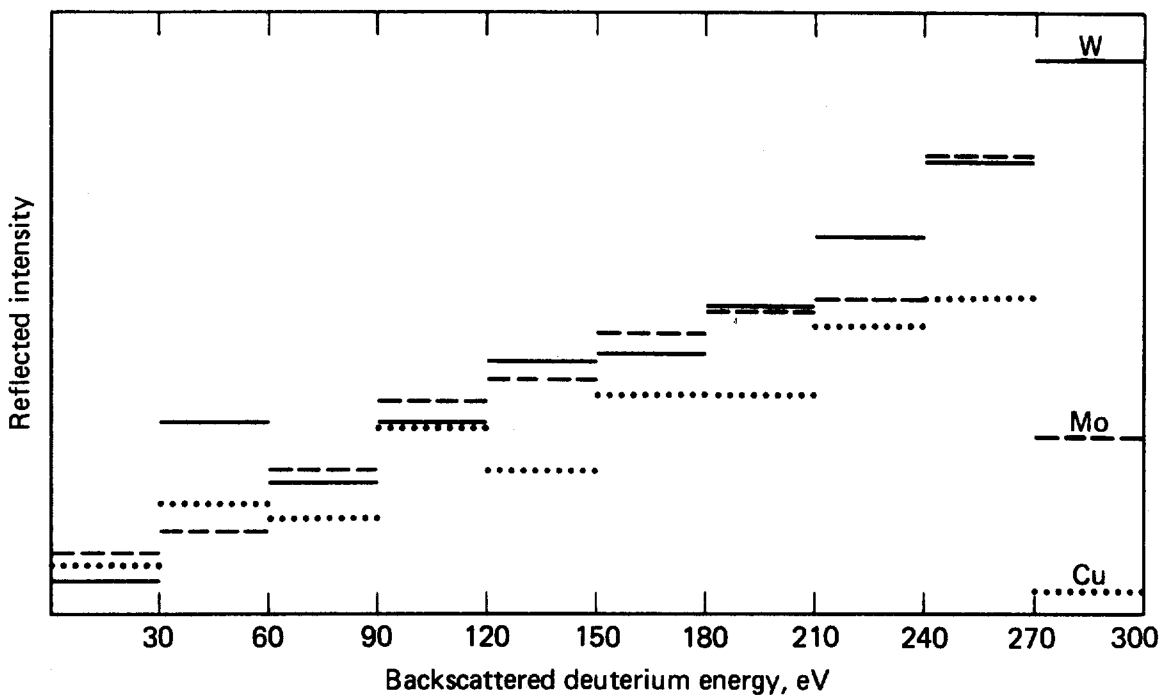
300 eV Deterium incident
150 eV
100 eV
50 eV
Reflected fraction, R_N
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Li
K
Ni
Cu
Mo
Ag
Cs
Hf
W
Pt
U
10
20
30
40
50
60
70
80
90
100
Atomic number

Fig. One



W
Mo
Cu
Reflected intensity
5
10
15
20
25
30
35
40
45
50
Backscattered deuterium energy, eV

Fig. Two



W
Mo
Cu
Reflected intensity
30
60
90
120
150
180
210
240
270
300
Backscattered deuterium energy, eV

Fig. Three

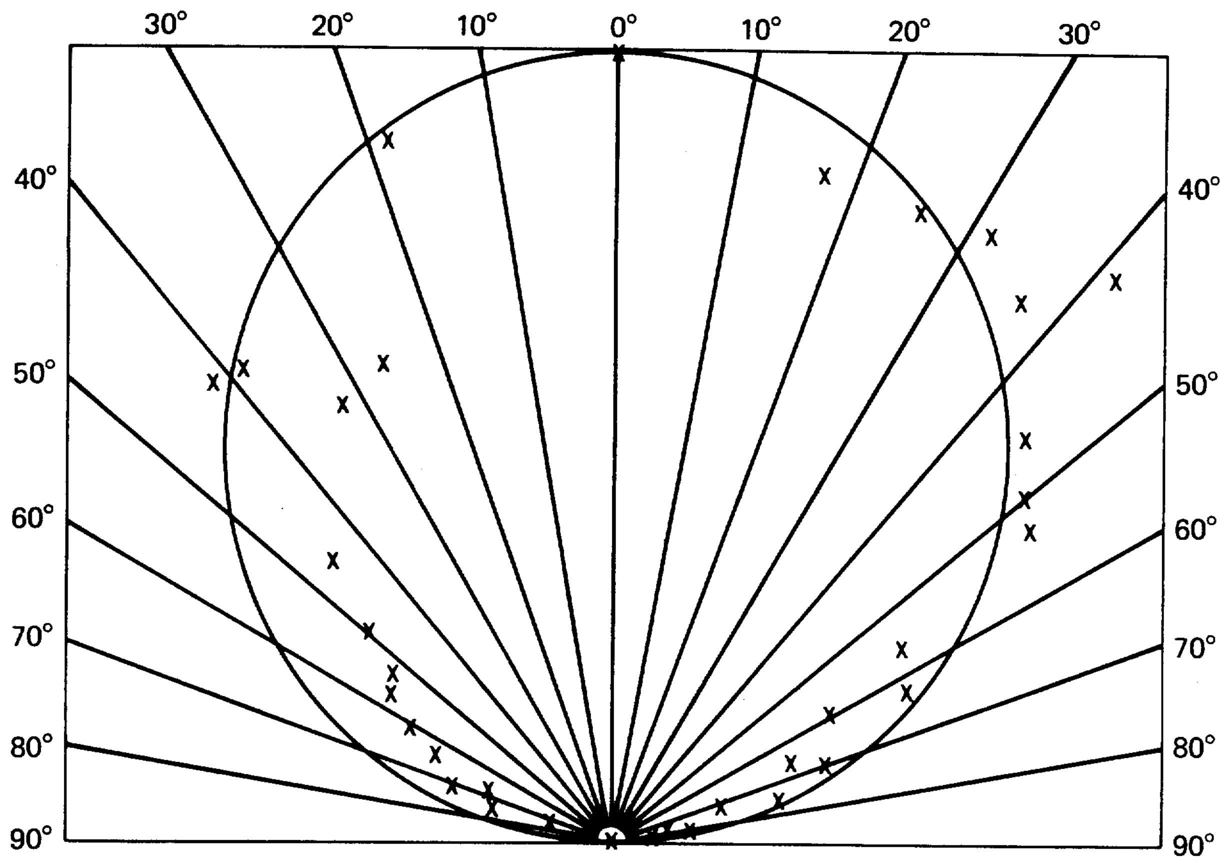


Fig. Four

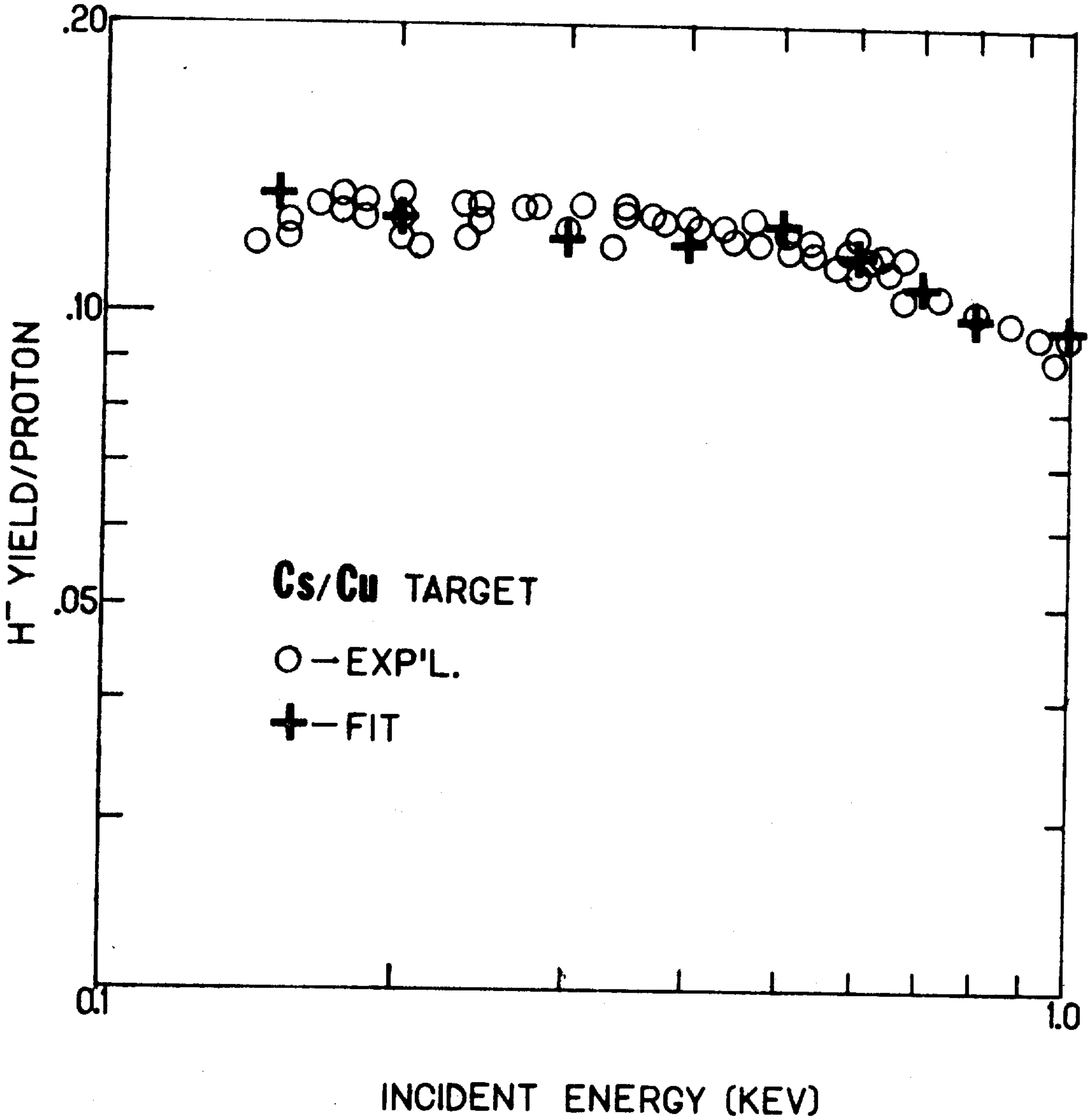


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Fig. Five

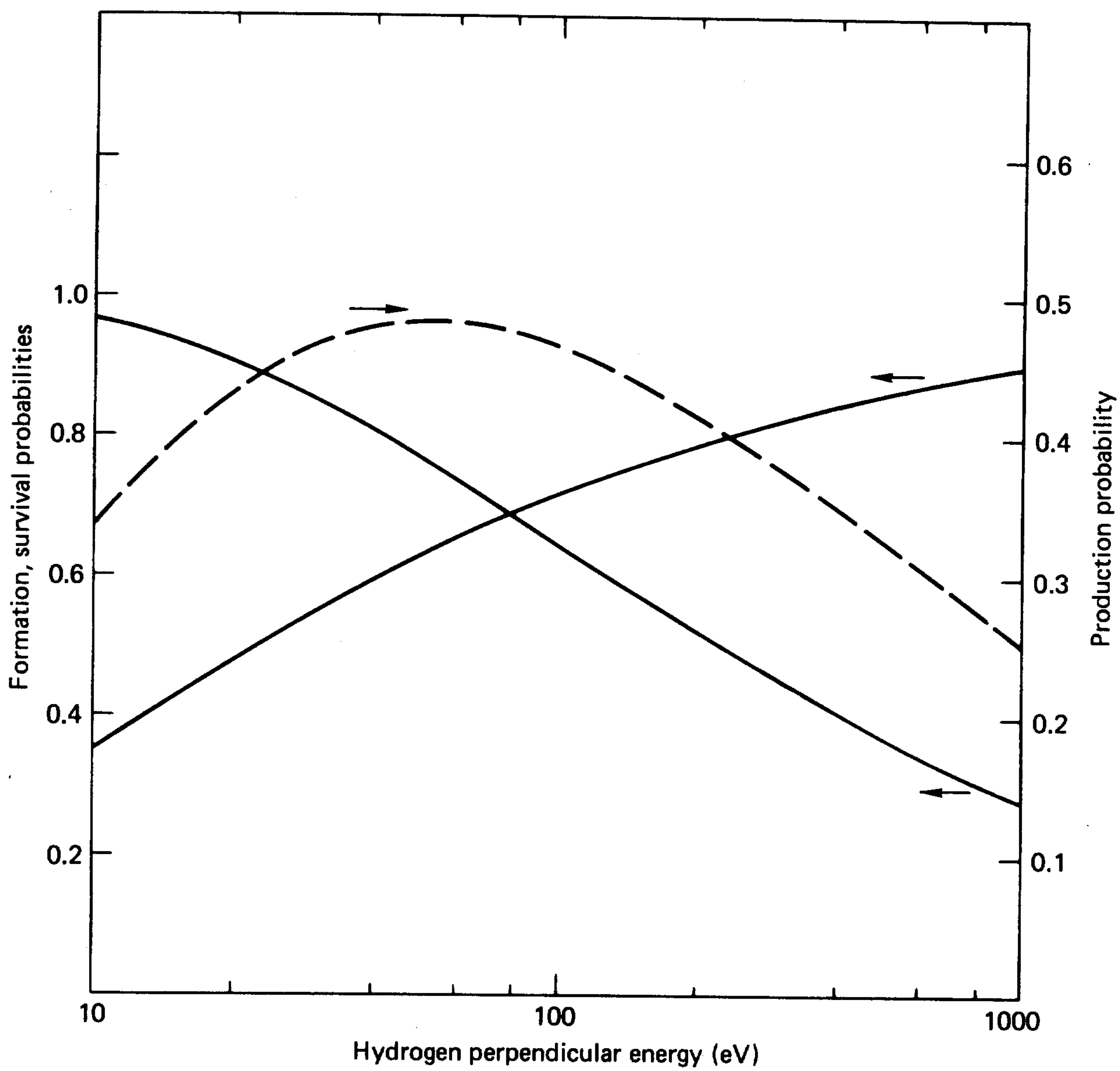
1.0
0.8
0.6
0.4
0.2
Formation, survival probabilities
0.6
0.5
0.4
0.3
0.2
0.1
Production probability
10
100
1000
Hydrogen perpendicular energy (eV)

Fig. Six